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The funds from this grant were used to support observations and analysis with the International Ultraviolet Explorer (IUE) satellite telescope. The main area of scientific research concerned the variability analyses of ultraviolet spectra of Active Galactic Nuclei, primarily quasars, Seyfert galaxies, and BL Lacertae objects.

The Colorado group included, at various times, the P.I. (J.M. Shull), Research Associate Dr. Rick Edelson, and graduate students Jon Saken, Elise Sachs, and Steve Penton. A portion of the work was also performed by CU undergraduate student Cheong-ming Fu. A major product of the effort was a database of all IUE spectra of active galactic nuclei. This database is being analyzed to obtain spectral indices, line fluxes, and continuum fluxes for over 500 AGN. As a by-product of this project, we implemented a new, improved technique of spectral extraction of IUE spectra, which has been used in several AGN-WATCH campaigns (on the Seyfert galaxy NGC 4151 and on the BL Lac object PKS 2155-304).

The papers that have resulted from our project are listed below, including several in preparation. Copies of the title pages are attached.

Publications:

Urry, C.M.,...Shull, J.M., et al. (1993) ApJ, 411, 614-631
"Multiwavelength Monitoring of the BL Lacertae Object PKS 2155-304. I. The IUE Campaign"

Shull, J.M. & Sachs, E.L. (1993) ApJ, 416, 536-545
"Variable C IV Absorption in the Seyfert Galaxy NGC 5548: A Connection to Broad Absorption Line Quasi-Stellar Objects?"

Edelson, R.,...Shull, J.M., et al. (1995) ApJ, 438, 120-134
"Multiwavelength Monitoring of the BL Lacertae Object PKS 2155-304. IV. Multiwavelength Analysis"

Korista, K.T.,...Shull, J.M. et al. (1995) ApJS, 97, 285-330
"Steps toward the Determination of the Size and Structure of the Broad-Line Region in Active Galactic Nuclei. VIII. An Intensive HST,IUE,Ground-Based Study of NGC 5548"

Multiwavelength Observations of Short Timescale Variability in NGC 4151.
I.Ultraviolet Observations (Crenshaw, D.M....Shull, J.M., et al., 1996 in prep.)
IV.Multiwavelength Analysis (Edelson, R.... Shull, J.M. et al., 1996, in prep.)

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MULTIWAVELENGTH MONITORING OF THE BL LACERTAE OBJECT PKS 2155−304. I. THE *IUE* CAMPAIGN

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ABSTRACT

Daily monitoring of PKS 2155−304 with the *IUE* satellite throughout 1991 November has revealed dramatic, large-amplitude, rapid variations in the ultraviolet flux of this BL Lac object. Many smaller, rapid flares are superposed on a general doubling of the intensity. During the 5^d period when sampling was roughly continuous, the rapid flaring had an apparent quasi-periodic nature, with peaks repeating every $\sim 0^d.7$. The short- and long-wavelength ultraviolet light curves are well correlated with each other, and with the optical light curve deduced from the Fine Error Sensor (FES) on *IUE*. The formal lag is zero, but the cross-correlation is asymmetric in the sense that the shorter wavelength emission leads the longer. The ultraviolet spectral shape varies a small but significant amount. The correlation between spectral shape and intensity is complicated; an increase in intensity is associated with spectral hardening, but lags behind the spectral change by ~ 1 day. The sign of the correlation is consistent with the nonthermal acceleration processes expected in relativistic plasmas, so that the present results are consistent with relativistic jet models, which can also account for quasi-periodic flaring. In contrast, currently proposed accretion disk models are strongly ruled out by the simultaneous optical and ultraviolet variability.

Subject headings: BL Lacertae objects: individual (PKS 2155−304) — galaxies: active — ultraviolet: galaxies

1. INTRODUCTION

The most puzzling aspect of active galactic nuclei (AGNs) has always been their high power output coupled with the small emission region inferred from rapid variability. The characteristics shared by the most rapidly variable objects, BL Lac objects and optically violently variable (OVV) quasars, collectively called "blazars," such as high (and variable) polarization, compact radio structure, a smooth continuum spectrum from radio through soft X-ray wavelengths, and superluminal motion, may owe their origin to a relativistic jet (Blandford & Rees 1978). The unreasonably high inferred radio brightness temperatures ($T \gg 10^{12}$ K; Quirrenbach et al. 1989) and flare quotients in excess of the Eddington-limited value assuming accretion efficiency η (Fabian 1979), $\Delta L/\Delta t > 2 \times 10^{42}\ \eta$ ergs s^{-2} (e.g., Feigelson et al. 1986; Morini et al. 1986), often exhibited by blazars, can most easily be explained by relativistic effects. The quantity $\Delta L/\Delta t$ is proportional to δ^5, where $\delta = (\gamma[1 - \beta \cos \theta])^{-1}$ is the kinematic Doppler factor describing relativistic motion with Lorentz factor γ (velocity β) at an angle θ to the line of sight.

In the last decade, considerable progress has been made interpreting the broad-band spectra of blazars in terms of models of inhomogeneous relativistic jets (Marscher 1980; Königl 1981; Ghisellini, Maraschi, & Treves 1985; Worrall et al. 1986; Hutter & Mufson 1986; George, Warwick, & Bromage 1988). These models have been very successful, in the sense that with a minimal number of parameters they usually fit the continuum spectrum over nearly 10 decades in wavelength. Unfortunately, the parameters of the model are rarely well determined because a variety of assumptions can produce acceptable fits for a large volume of parameter space. The degeneracy of multiple model solutions vanishes or is greatly

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VARIABLE C IV ABSORPTION IN THE SEYFERT GALAXY NGC 5548: A CONNECTION TO BROAD ABSORPTION LINE QUASI-STELLAR OBJECTS?

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ABSTRACT

This is the second in a series of papers examining variable absorption components in the broad emission lines of Seyfert 1 galaxies. In an *IUE* survey of a complete sample of CfA Seyfert galaxies, we find that at least 12% and perhaps as many as 27% of the objects show evidence of intrinsic absorption in C IV λ1549. In this paper, we use data from an 8 month *IUE* campaign on NGC 5548 to study the C IV absorption component. From the observed fluxes and C IV ionization conditions, we infer that the C IV absorption occurs within $(14\ \mathrm{pc})r_6^{-1/2}$ of the nucleus. The C IV absorption feature is blueshifted by ~ 1200 km s^{-1} from the systemic velocity of the galaxy and varies on a timescale of 4 days or less, indicating that $n_e \geq 5 \times 10^5$ cm^{-3} from recombination-response arguments. The C IV absorption equivalent width strongly anticorrelates with continuum flux at 1570 Å.

The broad-line region must be at least partially covered by the absorbing region, and the central wavelength of the broad-line region corresponds to that of the maximum absorption. Standard broad-line clouds cannot account for the absorption feature, and the absorbing material must be optically thin and dispersed in velocity space. We propose a relationship between broad absorption line (BAL) QSOs and Seyfert 1 galaxies with absorption, and we suggest that the latter may be a low-luminosity, low-redshift manifestation of the BAL phenomenon in quasars. The high frequency of occurrence may represent a statistical effect of outflow viewing angle on the sky.

Subject headings: galaxies: Seyfert — galaxies: individual (NGC 5548) — quasars: general — ultraviolet: galaxies

1. INTRODUCTION

NGC 5548 is one of a number of active galaxies that exhibit absorption lines in the core of selected ultraviolet emission lines (Voit, Shull, & Begelman 1987; Ulrich 1988). The blueshifts of these absorption features relative to the underlying emission line suggest an outflow of ionized gas from the galactic nucleus, similar to those seen in broad absorption line (BAL) QSOs (Weymann, Turnshek, & Christiansen 1985) in higher luminosity QSOs. This outflowing gas may also be related to the "extended emission-line regions" (Wilson & Heckman 1985; Unger et al. 1987), which often appear as conical emission geometries surrounding the nuclear regions (Pogge 1989; Cecil, Bland, & Tully 1990). However, there may be significant differences in both spatial location and gas density among these objects.

Several "absorption-line Seyferts" have been identified with the *IUE* satellite, most prominently the objects NGC 4151 (Bromage et al. 1985; Clavel et al. 1987), NGC 3561 (Voit et al. 1987), and NGC 5548 (this paper). These Seyferts show intrinsic absorption in C IV λ1549, N V λ1240, and (sometimes) Si IV λ1400. The lines of Mg II λ2800 and Lyα are usually absent in absorption. At higher redshift, the BAL QSOs appear to be a higher luminosity version of the same phenomenon, occurring in about 10% of high-redshift, radio-quiet QSOs (Stocke, Morris, & Weymann 1992). These authors also show that the BAL QSO phenomenon appears exclusively in radio-quiet QSOs. An extensive spectrophotometric study of BAL and non-BAL QSOs (Weymann et al. 1991) finds no significant differences, leading to the conclusion that all radio-quiet QSOs may exhibit BALs from some source viewing angle. In both BAL QSOs and absorption-line Seyferts, the nucleus of the active galaxy evidently is producing an outflow of ionized gas or clouds. Stocke et al. (1992) further suggest that the observed anticorrelation of the "BAL wind" with radio flux may arise if a jet is confined by the pressure of a dense interstellar medium in the host galaxy.

In this paper we propose a class of "BAL Seyferts" as a possibly related, low-luminosity manifestation of the phenomenon observed in high-redshift BAL QSOs. This connection was also mentioned by Stocke et al. (1992), based on the absorption lines seen in NGC 3516, NGC 4151, and similar objects. Statistical evidence for this proposal includes the following facts: (1) at least 12% and perhaps as many as 27% of the CfA Seyfert 1 galaxies show intrinsic C IV absorption; (2) at least 10% of Palomar-Green (PG) QSOs ($V \leq 15.5$) in the *IUE* archives show possible intrinsic absorption. Further work on the latter sample is currently underway with the *International Ultraviolet Explorer* (*IUE*) satellite. We concentrate here on NGC 5548, using *IUE* data from the 1988–1989 campaign (Clavel et al. 1991, hereafter C91) that provided intensive 4 day monitoring over an 8 month interval. The completeness of the C91 survey also makes NGC 5548 an ideal candidate to study for UV absorption and its response to the continuum variations. In § 2 we provide background on the "BAL Seyfert" phenomenon, describe the *IUE* observations and data reduction, and discuss our techniques for measuring the continuum flux, emission-line flux, and absorption equivalent width. In § 3 we present the

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MULTIWAVELENGTH MONITORING OF THE BL LACERTAE OBJECT PKS 2155−304. IV. MULTIWAVELENGTH ANALYSIS

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ABSTRACT

Simultaneous X-ray, ultraviolet, optical, infrared, and radio monitoring data were used to test and constrain models of continuum emission from the BL Lacertae object PKS 2155−304. Intensively sampled ultraviolet and soft X-ray light curves showed a clear temporal correlation, with the X-rays leading the ultraviolet by 2–3 hr. This lag was found to be significantly different from zero after an exhaustive comparison of four different techniques for measuring temporal correlations. Variations in the ultraviolet through optical wave bands were also all strongly correlated, with no measurable lag down to limiting timescales of $\lesssim$1–2 hr. This strong correlation extends to the near-infrared, but the less intensive sampling precludes measurement of any lag beyond an upper limit of $\lesssim$1 day. These lags and limits of the order of hours are much shorter than the most rapid observed single-band variations. Because of the very sparse radio sampling, it was not possible to measure quantitatively the correlation and lag with shorter wavelengths, but the data do suggest that the radio may lag the optical/ultraviolet by $\sim$1 week, with longer delays and weaker variations to longer radio wavelengths. The epoch-folding Q^2 statistic was used to test for periodicity, and no evidence for strict or quasi-periodicity was found in any of the light curves.

Because they lead the lower frequencies, the soft X-rays ($\lesssim$1 keV) cannot arise from synchrotron self-Compton scattering. These results also rule out the accretion disk model, which predicts a measurable lag between ultraviolet/optical wavelength bands and a correlation between hardness and brightness, neither of which were seen. They are consistent with the entire radio through X-ray continuum arising from direct synchrotron emission from a relativistic jet. However, the tapered jet model, in which the X-ray emission is produced closer in, has problems explaining the magnitude of the ultraviolet/X-ray lag, because the

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STEPS TOWARD DETERMINATION OF THE SIZE AND STRUCTURE OF THE BROAD-LINE REGION IN ACTIVE GALACTIC NUCLEI. VIII. AN INTENSIVE *HST*, *IUE*, AND GROUND-BASED STUDY OF NGC 5548

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MULTIWAVELENGTH OBSERVATIONS OF SHORT TIME-SCALE VARIABILITY IN NGC 4151. I. ULTRAVIOLET OBSERVATIONS

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MULTIWAVELENGTH OBSERVATIONS OF SHORT TIME-SCALE VARIABILITY IN NGC 4151. IV. MULTIWAVELENGTH ANALYSIS

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